eRD20: Developing Simulation and Analysis Tools for the EIC

ESC

EIC SOFTWARE CONSORTIUM

Markus Diefenthaler

Software Initiative for the EIC

EIC Software Consortium

Existing EIC Software

ANL TOPSiDE detector concept (ILC software variant)

BNL BeAST detector concept: EICroot (FairRoot variant)

BNL ePHENIX detector concept (fun4all)

JLAB JLEIC detector concept (GEMC → eJANA)

Software Review by EIC Community in November 2017

- **Actively maintained** ANL software, fun4All , EicRoot, then GEMC and now eJANA
- The analysis environments for the EIC will be chosen when the EIC experimental collaborations will form.
- Until then, we will examine the **requirements** for the EIC analysis environment and work on the **R&D** aspects of the EIC analysis environment.

EIC Software Consortium

ESC

EIC SOFTWARE CONSORTIUM

Goals and focus

- work on common interfaces among EIC simulation tools
- explore new avenues of software development (e.g., AI)
- **reach out to the EIC community**
    - communicate present status of EIC software
    - bring existing EIC software to end users
    - produce publicly available consensus-based documents on critical subjects
    - provide vision for the future

ESC members

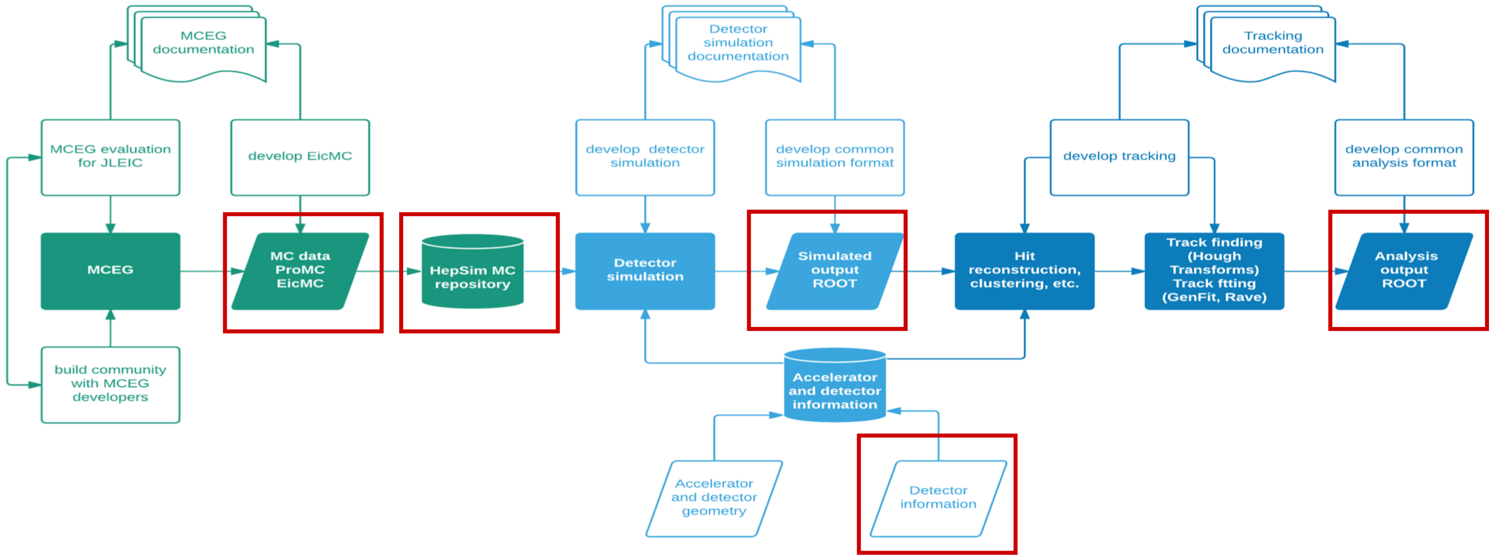
ANL, BNL, JLAB, LUND, INFN, SLAC, Trieste, W&M (→ Manitoba)

Part of EIC Generic Detector R&D program

Common interfaces

Advice from ILC effort

- facilitate interoperability
- focus on exchange detector designs and data
  - get the event data model right and keep it open
  - pick a detector definition which is exchangeable



Norman Graf (SLAC)
"It's very difficult to ~~herd cats~~ keep physicists from re-inventing the wheel and writing new software packages."

MCEG

BeAST container (EICroot)

ePHENIX container (fun4all)

JLEIC container (eJANA)

TOPSiDE container

reconstruction

ESC Initiatives

Engaging with the wider community

EICUG Software Working Group

EIC Software users and their requests

Ongoing EIC project
Software ✓
Documentation ✓
Requests none

Example projects
- ANL:TOPSiDE LDRD
- BNL: ePHENIX LoI
- BNL: eRHIC preCDR
- JLAB: JLEIC preCDR

Focus on (pre)**CDRs and site selection as part of CD1** using existing lab software

EIC User Group
Common Software ✗
Common Documentation ✗
Requests software, documentation

Focus on preparation of EIC collaborations
- further develop EIC Science
- examine detector requirements
- work on detector designs
- work on detector concepts

requires simulations of physics processes and detector response

EIC Generic Detector R&D projects
Software ✓
Documentation ✗ - ✓
Requests common software

Request from Thomas Ullrich, manager of the R&D program:

Why we urgently need a
- common (EIC-wide)
- easy to use*
- capable

detector simulation software

EIC Software Meeting on Detector and Physics Simulations

Wednesday Jul 10, 2019, BNL

Thomas Ullrich (BNL)

* for a grad-student/postdoc with moderately good computing skills

Charge for EICUG Software Working Group

The EICUG Software Working Group's **initial focus** will be on **simulations of physics processes and detector response to enable quantitative assessment of measurement capabilities and their physics impact**. This will be pursued in a manner that is **accessible**, **consistent**, and **reproducible** to the EICUG as a whole.

It will embody simulations of all processes that make up the EIC science case as articulated in the white paper, eventually integrating new processes under request and with the help of interested communities within the EICUG. The Software working group is to engage with new major initiatives that aim to further develop the EIC science case, including for example the upcoming INT program(s), and is anticipated to play key roles also in the preparations for the EIC project(s) and its critical decisions. The working group will build on the considerable progress made within the EIC Software Consortium (eRD20) and other efforts. The evaluation or development of experiment-specific technologies, e.g. mass storage, clusters or other, are outside the initial scope of this working group until the actual experiment collaborations are formed.

The working group will be open to all members of the EICUG to work on EICUG related software tasks. It will communicate via a new mailing list and organize regular online and in-person meetings that enable broad and active participation from within the EICUG as a whole.

EIC Generic Detector R&D projects

Recommendation from January 2019

"The feedback from the user community indicates that there is a keen desire to have access to reliable and easy simulation and reconstruction frameworks. It seems that there remains a threshold for users to quickly engage in Monte Carlo simulations to carry out an end-to-end evaluation of various detector designs and study the EIC physics performance for different detector configurations.[...] The effort on providing common interfaces is strongly supported"

EIC Software Groups (beyond the simulation effort at the labs)

High Energy Physics

CERN ROOT
Possible collaboration

HEP Software Foundation
Started collaboration

MCnet
Started collaboration

SLAC Geant4
Established collaboration

Nuclear Physics

EIC Software Consortium
Community Endorsement ✗
Funding ✓

Same software suite Seamless data processing from DAQ to data analysis using AI

EIC Streaming Readout Consortium
Community Endorsement ✗
Funding ✓

EICUG Software Working Group
Community Endorsement ✓
Funding ✗

EIC Software initiative for community

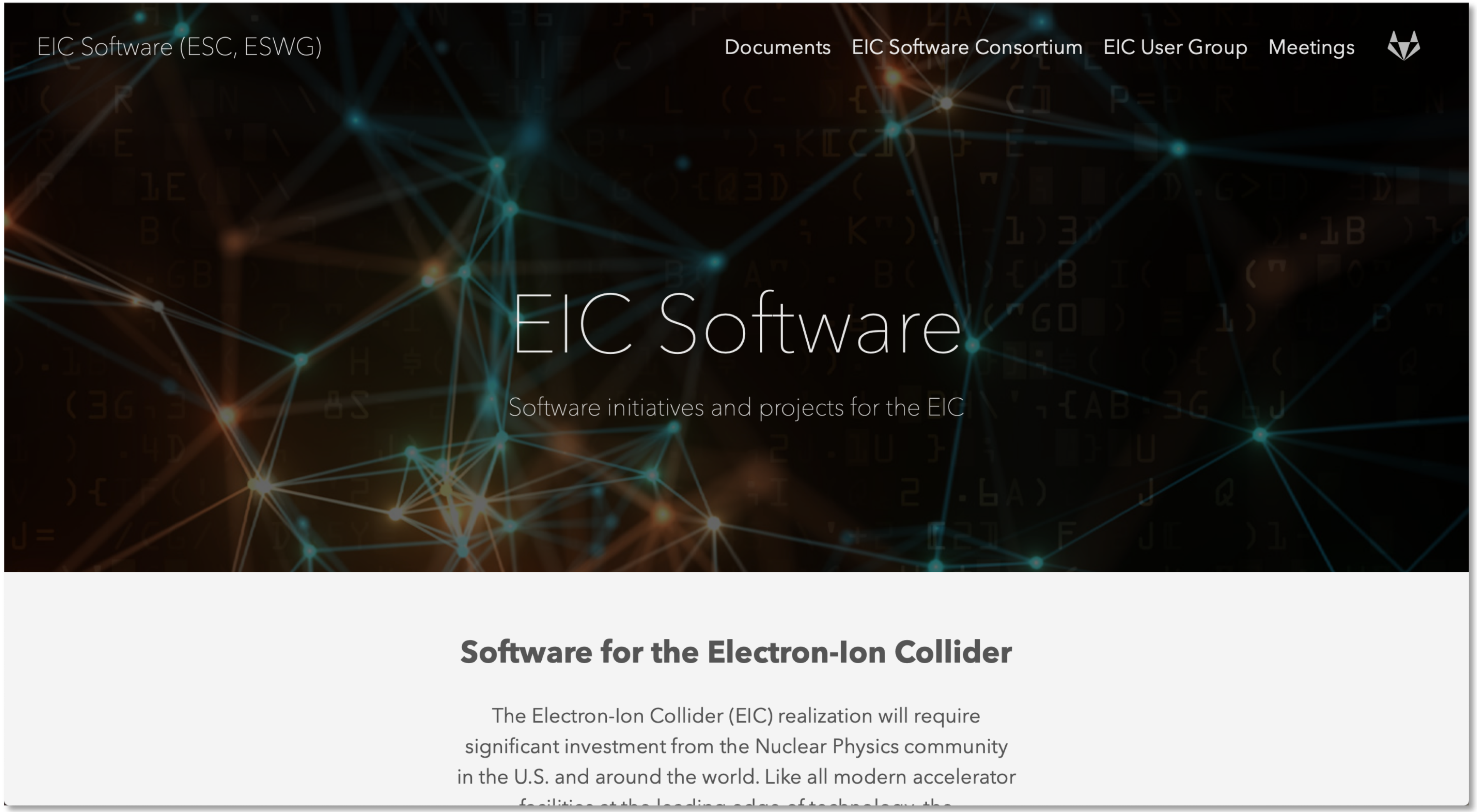
Workflow environment for EICUG

to use (tools, documentation, support) **and**

to grow with user input (direction, documentation, tools)

EIC Software Meeting

Single point of entry



EIC Software website https://eic.gitlab.io

User interface for EIC simulations for EICUG

ejana-gui container image

JupyterLab web interface

ejana-app container image

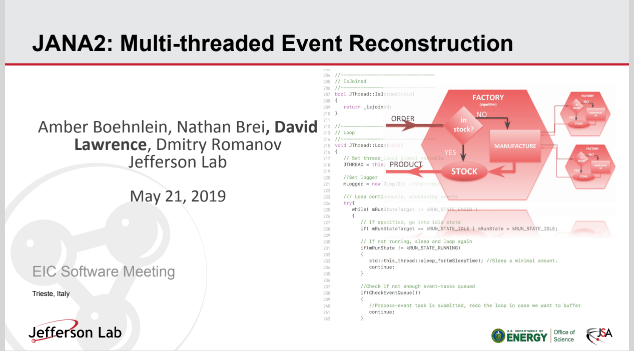
eJana

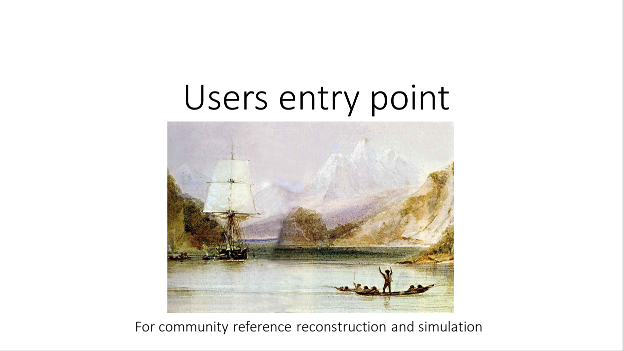
Fast simulations (current focus)
Monte Carlo event generators
eic-smear used for EIC Whitepaper

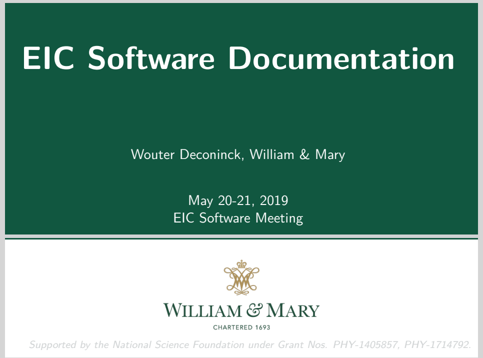
TBD Alterative for fast simulations
Monte Carlo event generators
Geant4 in fast mode

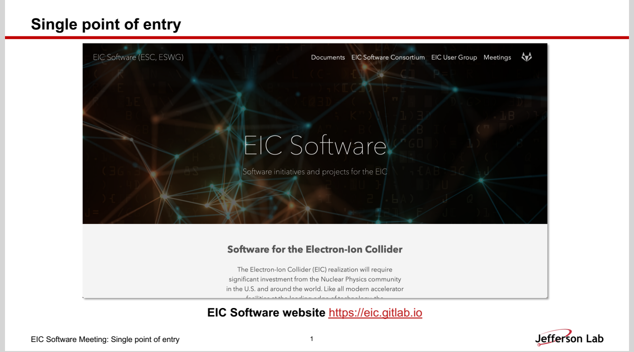
Full simulations
Monte Carlo event generators
Geant4 (to-be-unified)
Event reconstruction toolkit

Detailed Status Reports









Software design

Dmitry Romanov (JLAB)

simple	JupyterLab web interface
moderate	analysis scripts, python
complex	eJANA, plugins, C++
expert	JANA, eic-smear, ROOT, Geant4

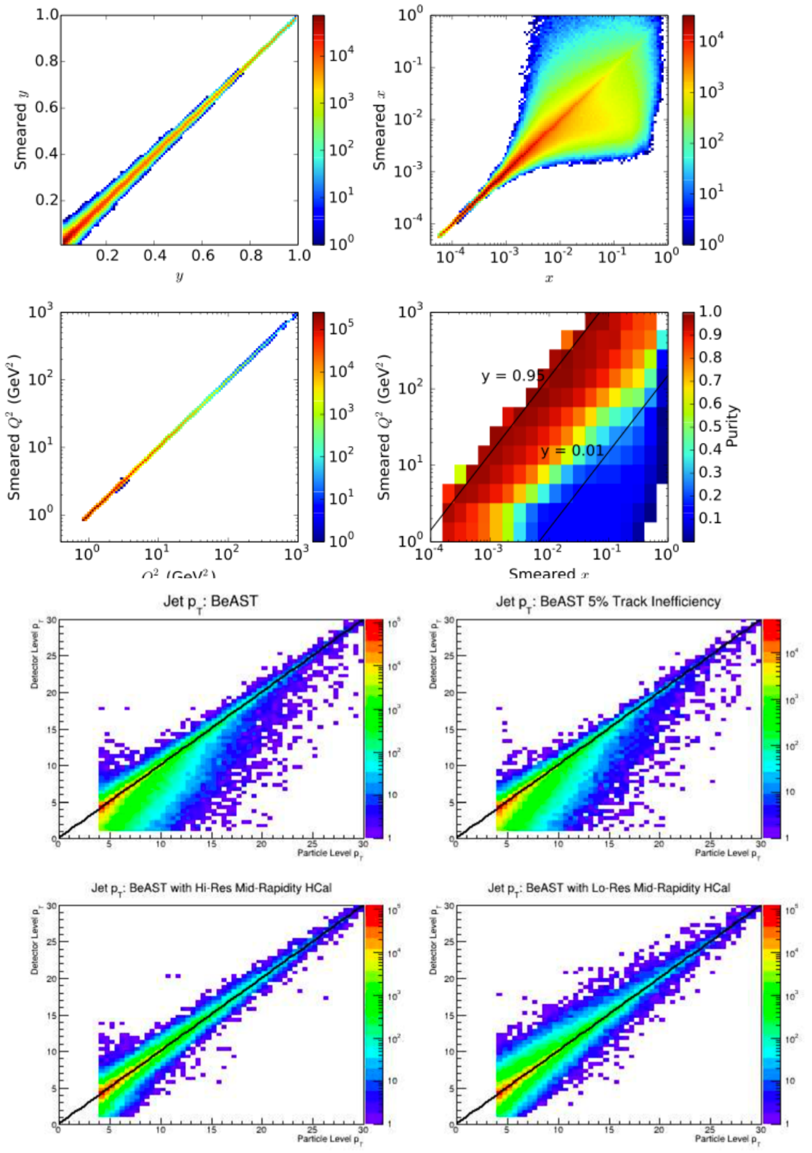
Escaping complexity scaling trap

- provide interfaces to internal layers
- interaction between layers must be clear

Modularity each layer must be replaceable

eic-smear

Alexander Kiselev, Kolja Kauder (BNL)



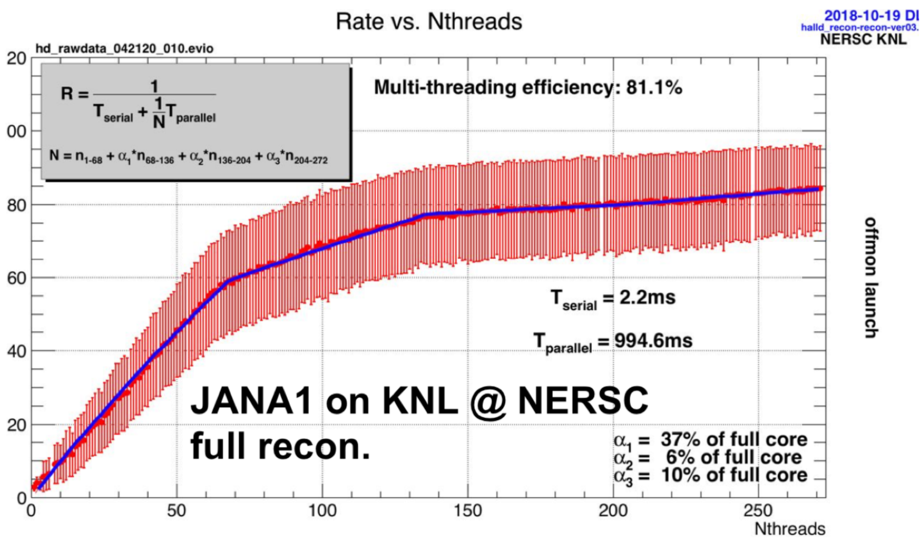
Fast simulations using ROOT, ideal for questions like

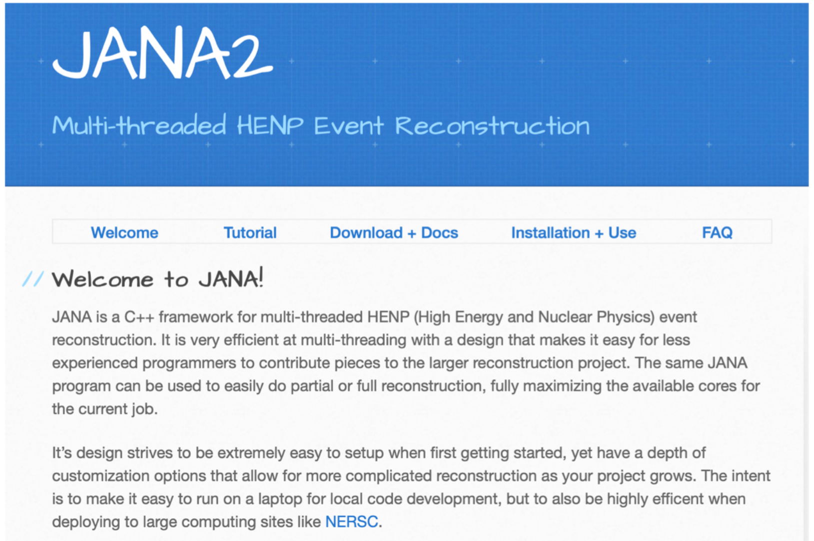
- *"Given a (known) detector performance, how well can I measure some physics observable(s)?"*
- *"If I need to measure X with to some precision, what detector performance do I need?"*
- Used extensively for **EIC White Paper**

Features

- interface to MCEGs for ep and eA
- smearing of overall detector performance:
  - can be easily modified in user code
  - includes acceptance effects
  - parametrizations for BeAST, ePHENIX, and ZEUS available
- ROOT trees for MC Truth and smeared information

EICUG Adapted as community tool for fast simulations





JANA C++ event processing framework

- **factory model** on demand interface, user-centered design
- multi-threaded with > 10 years experience
- **plugin support** provide mechanism for many physicists to contribute, multi-threading external to contributed code (parallelizer)

JANA2 under development (JLAB LDRD)

- take advantage of new C++ standards
- Python interface
- part of Streaming Readout Grand Challenge at Jefferson Lab (C++ streamed events processing framework)

e^{JANA} - Community reference reconstruction

Dmitry Romanov (JLAB)

e^{JANA} - stands for EIC JANA

- Basic reconstruction
- Physics analysis
- **Users detector codebase integration**

Any existing C++ (or even others) code can be:
- compiled as JANA plugin
- run parallelized in eJANA
- accessed by other plugins

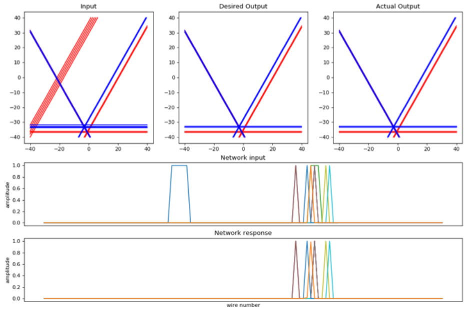
Reconstruction

- **Tracking** - Genfit
- **Vertex finding** – Rave
- **Physical analysis**:
  – ROOT C++ or
  – Python data science tools (Jupyter, Seaborn, Pandas, etc.)

ESC summer students

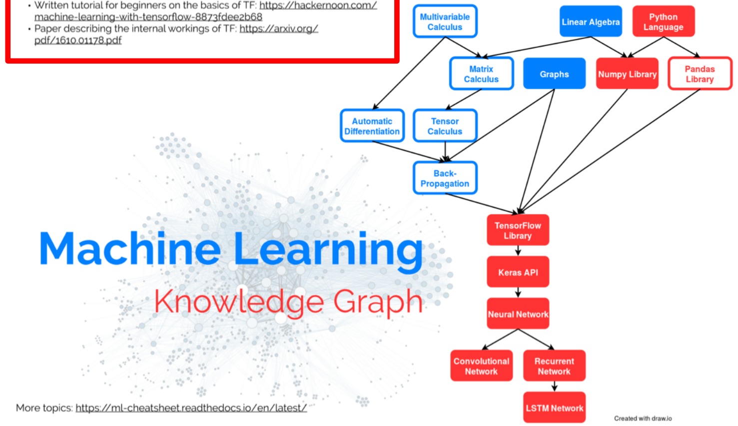
Wouter Deconinck (W&M, Manitoba)

Track finding in Jlab 12 data



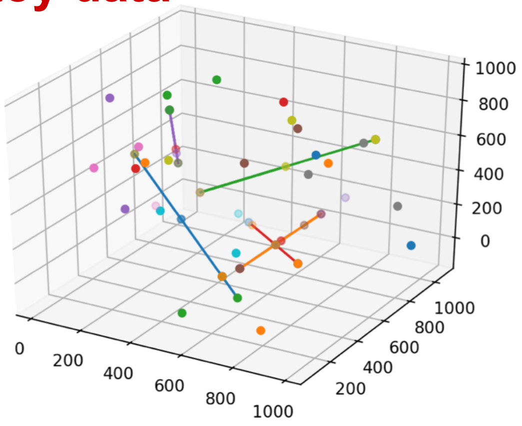
TensorFlow (TF)

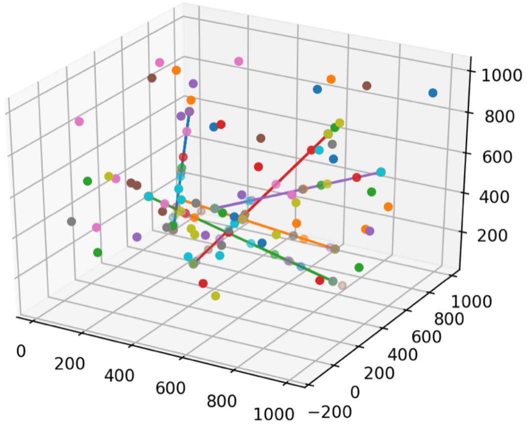
- Repository of Jupyter notebook TF tutorials for beginners: https://github.com/Hvass-Labs/TensorFlow-Tutorials
- Repository of Jupyter notebook TF tutorials for beginners: https://github.com/nlintz/TensorFlow-Tutorials
- Written tutorial for beginners on the basics of TF: https://www.datacamp.com/community/tutorials/tensorflow-tutorial
- Written tutorial for beginners on the basics of TF: https://hackernoon.com/machine-learning-with-tensorflow-8873fdee2b68
- Paper describing the internal workings of TF: https://arxiv.org/pdf/1610.01178.pdf



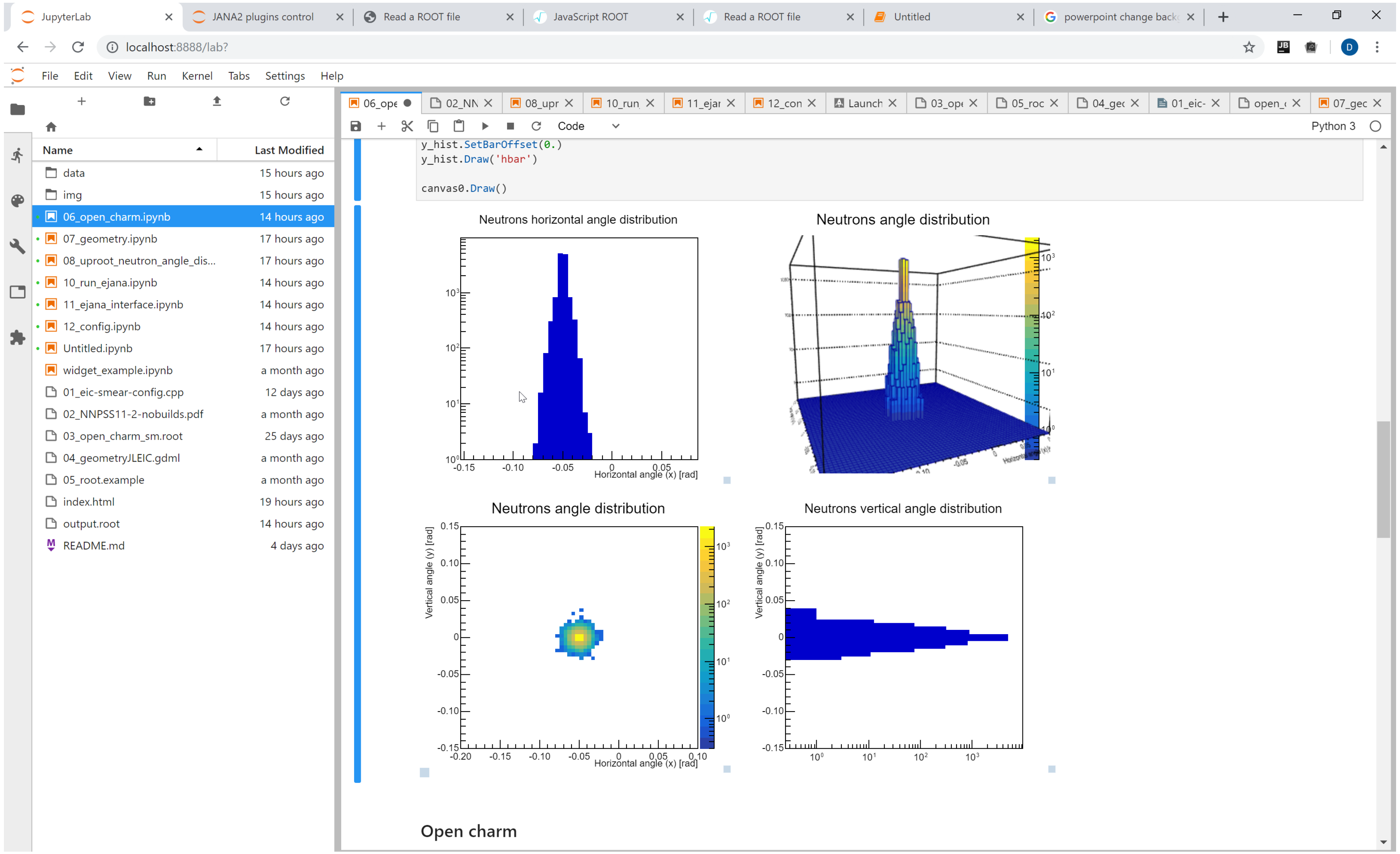
Track finding in toy data

using JLab JupyterHub at https://jupyter.jlab.org/





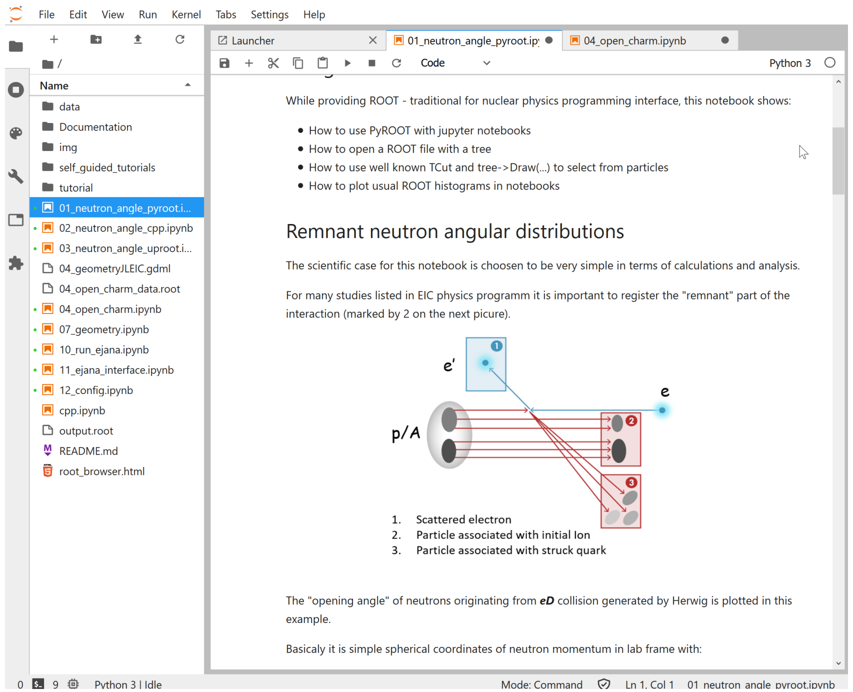
Workflow oriented interactive environment based on JupyterLab

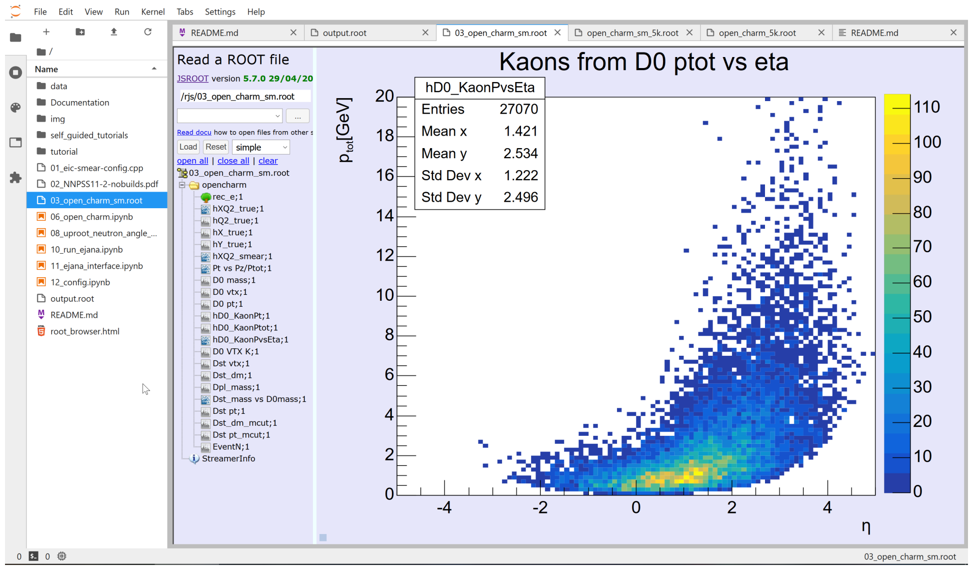


Motivation for JupyterLab

Project Jupyter

- bridge between modern Data Science and traditional Nuclear Physics methods
- self documenting

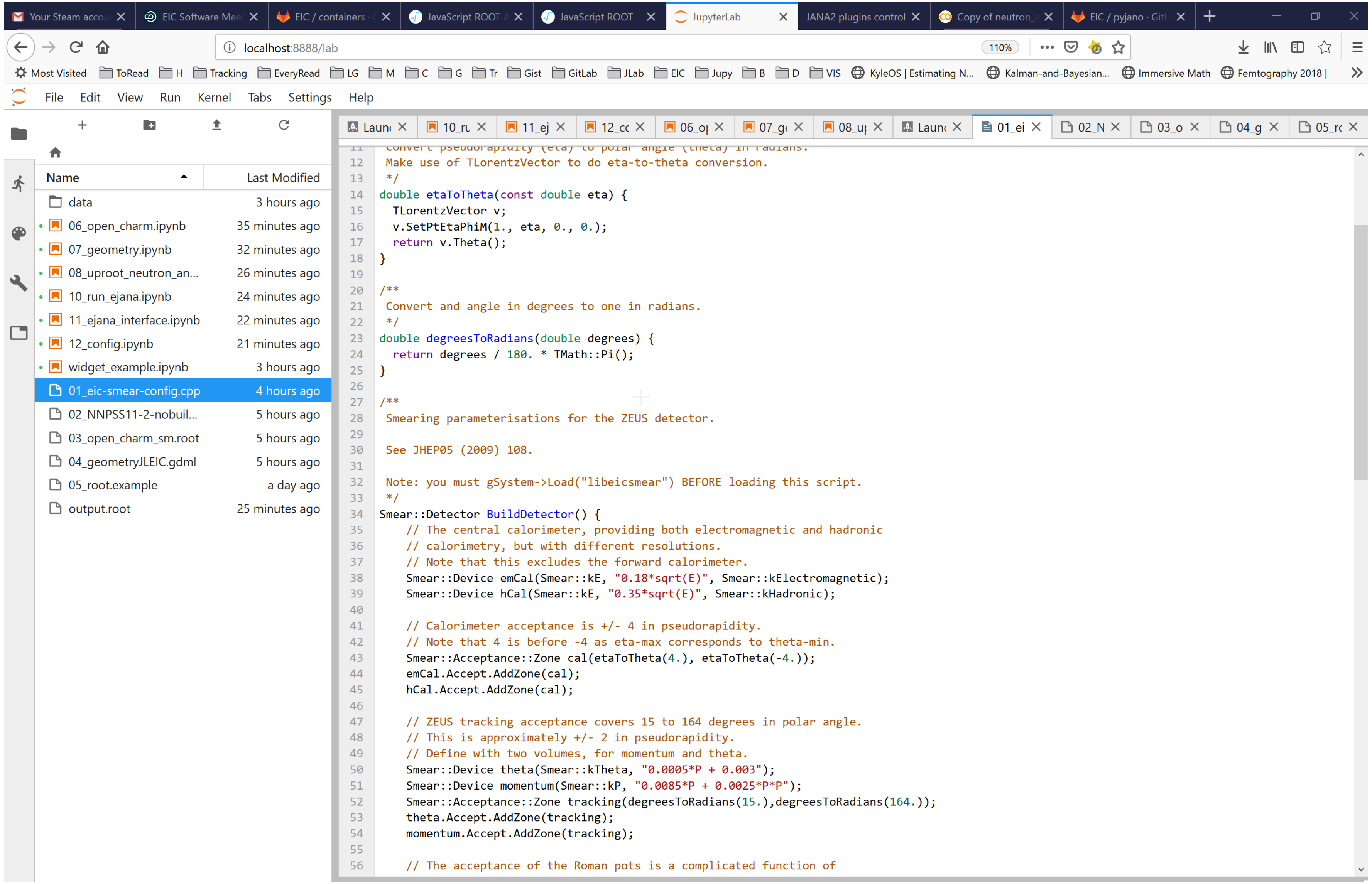




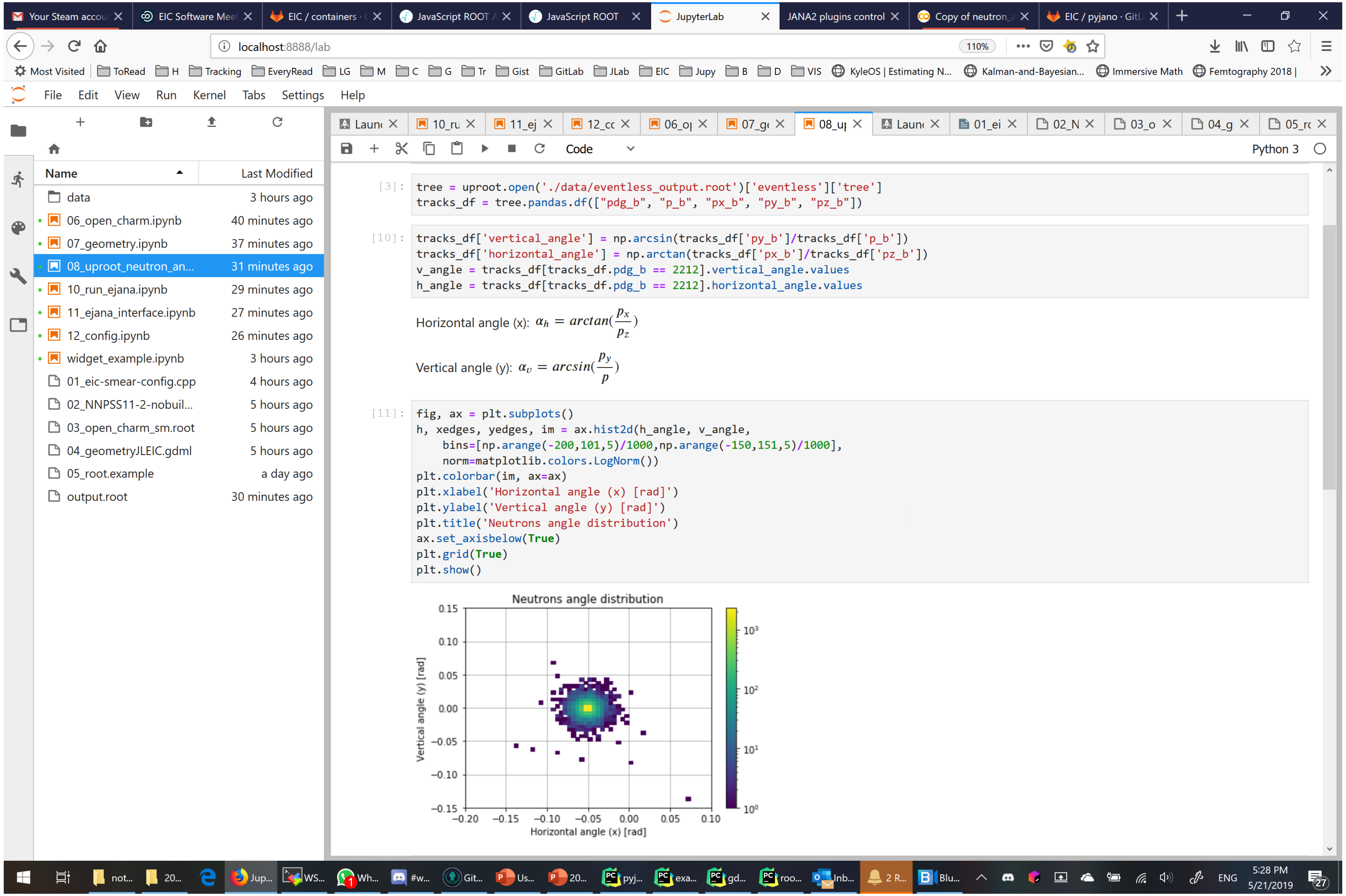
Ready to be

- cloud-based collaborative workspace
- medium for analysis, studies, reports (helping with reproducibility problem)

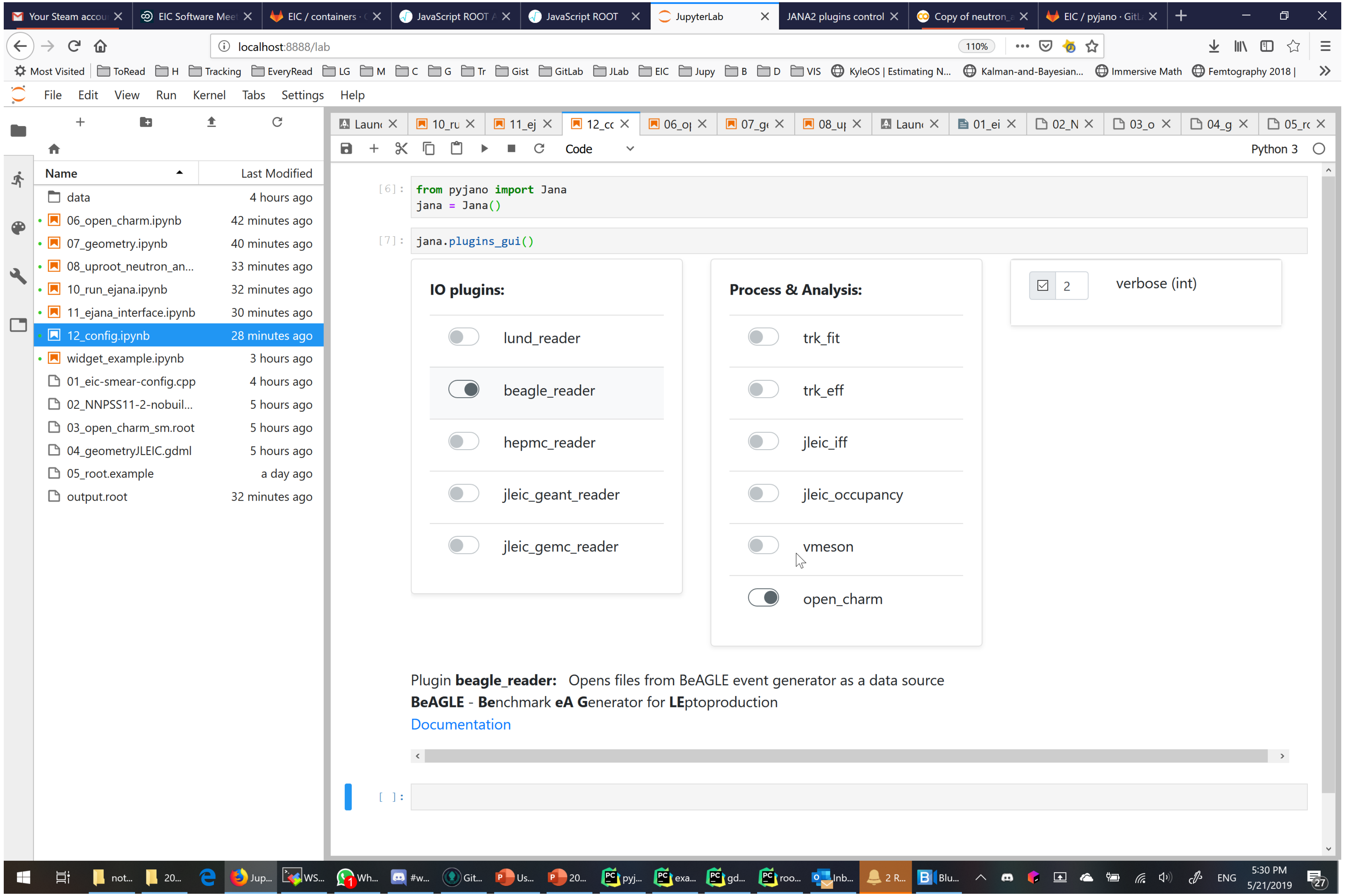
Complex layer: Interact with code



Moderate layer: Jupyter notebooks



Simple layer: Interactive vidgets



EIC Software Meeting on Detector and Physics Simulations

EIC Software Meeting on Detector and Physics Simulations

Wednesday 10 Jul 2019, 09:00 → 15:00 US/Eastern

2-160 (BNL Physics)

Andrea Bressan (Trieste), Markus Diefenthaler (Jefferson Lab), Torre Wenaus (BNL)

35 participants

Description

The Electron-Ion Collider User Group (EICUG) is organizing an EIC Ad-hoc Meeting on detector and physics simulations:

We will work out the requirements for simulation tools including geometry exchange between the eRHIC and JLEIC concepts and plan next steps for common tools for the EICUG. The work will be also relevant for TOPSiDE and other detector concepts for the EIC.

The goal of the meeting is to clarify the strategy for EIC detector and physics simulations and to meet on the time scale of FY19/FY20 the requirements for common tools and documentation in the EICUG. We would like to include all EIC Software initiatives in our discussion.

The meeting will be held at BNL on July 10, prior to the EIC Generic Detector R&D meeting on July 11-12, and will include presentations from HEP and NP experts as well as discussions with EIC Software developers.

The meeting has a hard finish at 3pm (we lose the room).

If you wish to attend in person and do not have a current BNL badge, please contact Torre Wenaus (wenaus@gmail.com, 631-681-7892) as soon as possible. Also contact Torre with any BNL related issues in general.

BlueJeans: https://bluejeans.com/920347364

Request for common, easy to use simulation tools

Thomas Ullrich (BNL)

Detector R&D and Simulations (Case 1)

- For almost all proposed detector R&D the Committee has and does request extensive simulations showing the concept is sound before substantial money is released for hardware/prototyping/test beams etc.
  - Geant simulations are mature and sophisticated enough to allow one to test the validity of the proposed concept and establish the detector performance to good accuracy
  - In most cases only GEANT simulations are needed
    - no need for sophisticated framework
    - no need for elaborate tracking software
  - The key issue in all cases is the detector description
    - geometry
    - materials

3

Detector R&D and Simulations (Case 2)

- Optimization
  - No detector concept is perfect from the start
  - Multi-parameter problems
    - Example Si-vertex detectors: # disks/layers, position of disks/layers, pixel size etc.
    - Tracking/RICH: composition of gases, voltages, readout layers (GEM), etc
  - It is impossible to build and test prototypes for all possible configurations - phase space is too big. Often simulations are the only way to find the right parameter set
- Simulations are mandatory here

4

Why “easy accessible and usable”?

- Many R&D groups are also involved in other projects that have a mature simulation setup (e.g. CMS, PANDA, COMPASS)
- If the EIC does not provide a common and easy simulation setup the chances are high groups will either use what they are used to or even go to vanilla Geant4
- This makes the situation even worse

- Note that other groups (e.g. ILC) have solved this successfully. Changing one detector to another is simply a matter of one switch. This makes it easy for groups working on certain sub-detectors to see how it fits and performs in whatever setup is available

8

Keep Context in Mind

- Users within the R&D community are **not** looking for a full flashed-out framework at this time
- A simple *lite setup* with a well defined geometry description “standard” might get them a long way as long if it is EIC wide and easy to use
- It is understood that a complete geometry/material package has to fulfill many tasks: simulations, reconstruction, all with condition DB interface, but this is something the collaborations will have to work out later. If the EIC User Group finds a workable solution now, chances are high that it will be picked up by the actual collaborations later.

9

Plans and actions

Torre Wenaus (BNL)

- agree on detector naming conventions
- agree on G4 C++ as the basis of detector description for now (access to all G4 volumes including new recommended ones like tessellated solids)
  - 3 of the 4 approaches (not EicRoot) can work with C++ G4 detector descriptions
  - make the (inevitable) framework-specific adaptation layer needed around the C++ as thin as possible
- agree on how structs for parameters are defined and managed
  - 'numbers in the code' is not necessarily a bad thing if they are managed carefully. Coming to commonality on a more long term solution like DB is a bigger issue (and not on Thomas' 'now' list)
- agree on API/class design for sensitive detector stepping action/digi
- agree on hits output structure
  - hits structure - can we agree on that? depends on detector and how reco is handled afterwards
  - even without this we've agreed on enough to satisfy Thomas
- common repository we point people to when they come along with a detector model to plug in
- deliverable: the simple document and template(s) we give to the user on how to implement and integrate their new subdetector in the detector concepts via our common Geant4 infrastructure
  - time frame?
    - by end of the fiscal year (end Sep), have made the agreements concrete in a document
    - for implementation…?
- deliverable: an updated/agreed document of the requirements
- need follow-up meeting on participation, who will do what by when
  - what resources do we have and how do we use them

Meeting schedule

Date	Topic(s)
05/20 – 05/22	EIC Software Meeting in Trieste, Italy
06/27	Benchmarks and validation (only remote)
07/10	**EIC Software Meeting on detector and physics simulations**
07/23	Tutorial during EICUG Meeting in Paris, France
08/	Summer break
09/24	Geant4 Technical Forum on EIC
to be annouced	

Geant4 Technical Forum at Jefferson Lab

Makoto Asai (SLAC)

- Geant4 Technical Forum will be held at Jefferson Lab on Tuesday, September 24 2019, as a part of the Geant4 Collaboration Meeting.
  - 16:00-18:00 US Eastern time (22:00-24:00 Central European time)
- This Technical Forum is highlighting EIC:
  - Geant4 developers will update the EIC community of the recent and ongoing developments that are relevant for EIC,
  - Requirements and concerns from the EIC community should be presented,
  - and discussed.
- Please keep Makoto and me informed on
  - What you want to hear from Geant4 developers, and
  - What you want to tell / argue to Geant4 developers

Markus Diefenthaler
mdiefent@jlab.org

FY20 budget request

Funds for hiring a postdoctoral researcher of USD 120,000

- works solely on the community tools for physics and detector simulations including geometry exchange between eRHIC and JLEIC and BeAST, ePHENIX, JLEIC, TOPSiDE detector concepts
- service for the EIC and in particular Detector R&D communities: support for using the tools and for integrating existing detector designs and reconstruction algorithms into the community tools

Travel funds of USD 20,000

- in-person meetings to work together on key tasks
- invite scientists that are essential to the R&D effort

Budget scenarios

- Nominal budget (100%): USD 140,000
- Nominal budget (-80%): USD 20,000 (only travel)

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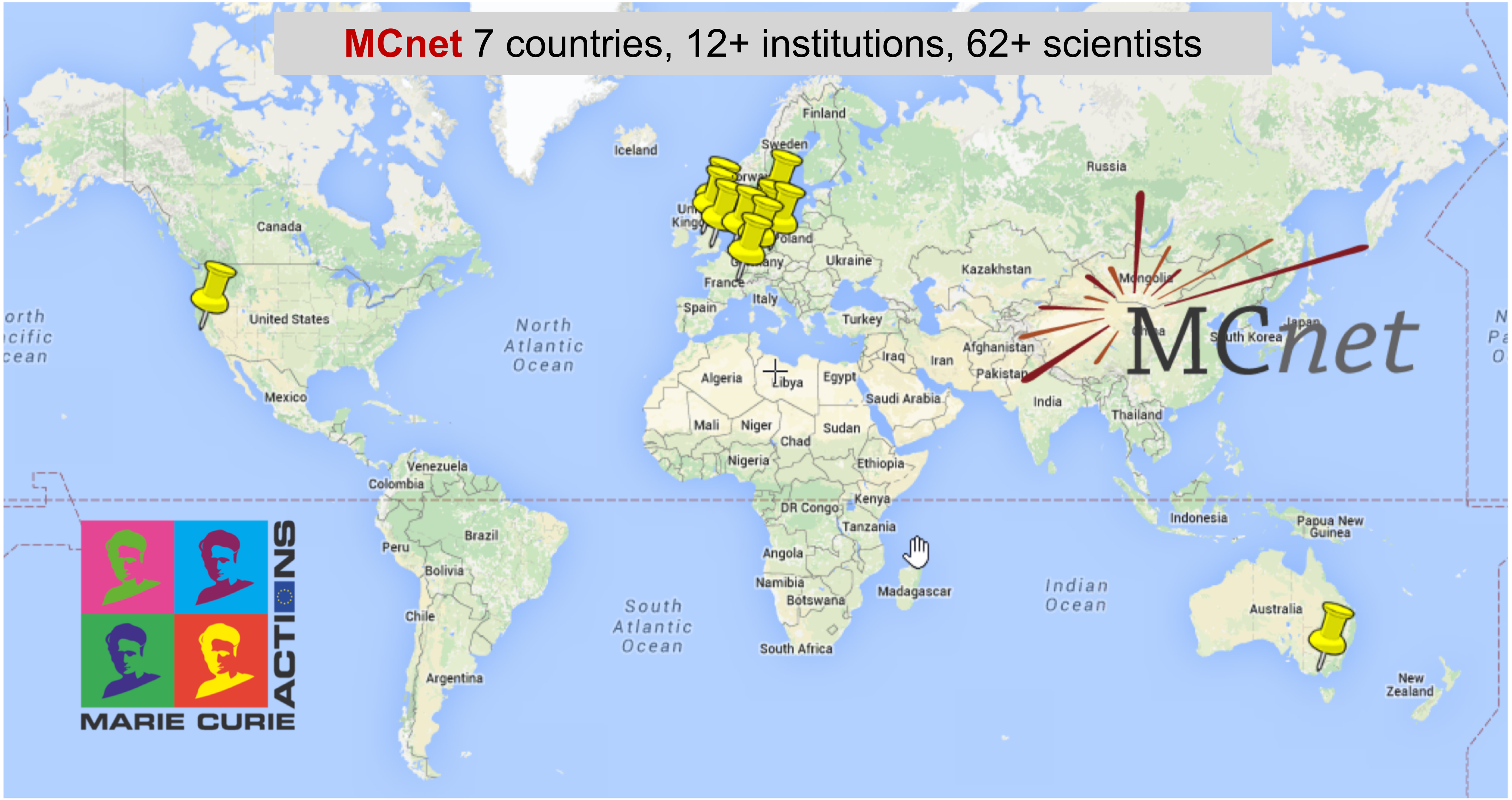
Additional slides

MCEG Initiative

MCEG Developers



Workshops: MCEGs for future ep and eA facilities

MCEG2018 19–23 March 2018

- Started as satellite workshop during POETIC-8

POETIC 8
8th International Conference on Physics Opportunities at an ElecTron-Ion-Collider
19-23 March 2018, University of Regensburg

- Collaboration EICUG-MCnet

Goal of workshop series

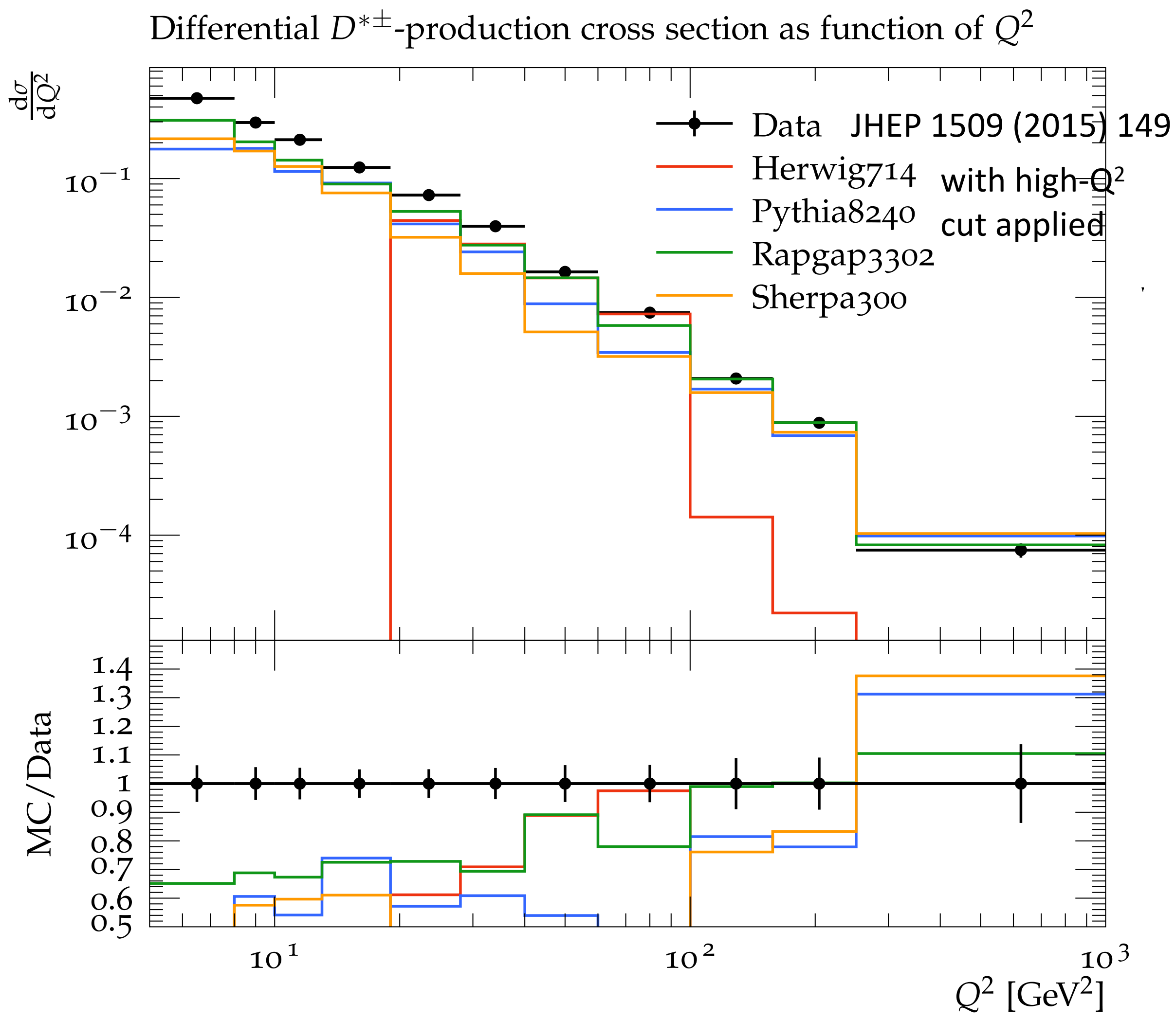
- Requirements for MCEGs for ep and eA
- R&D for MCEGs for ep and eA

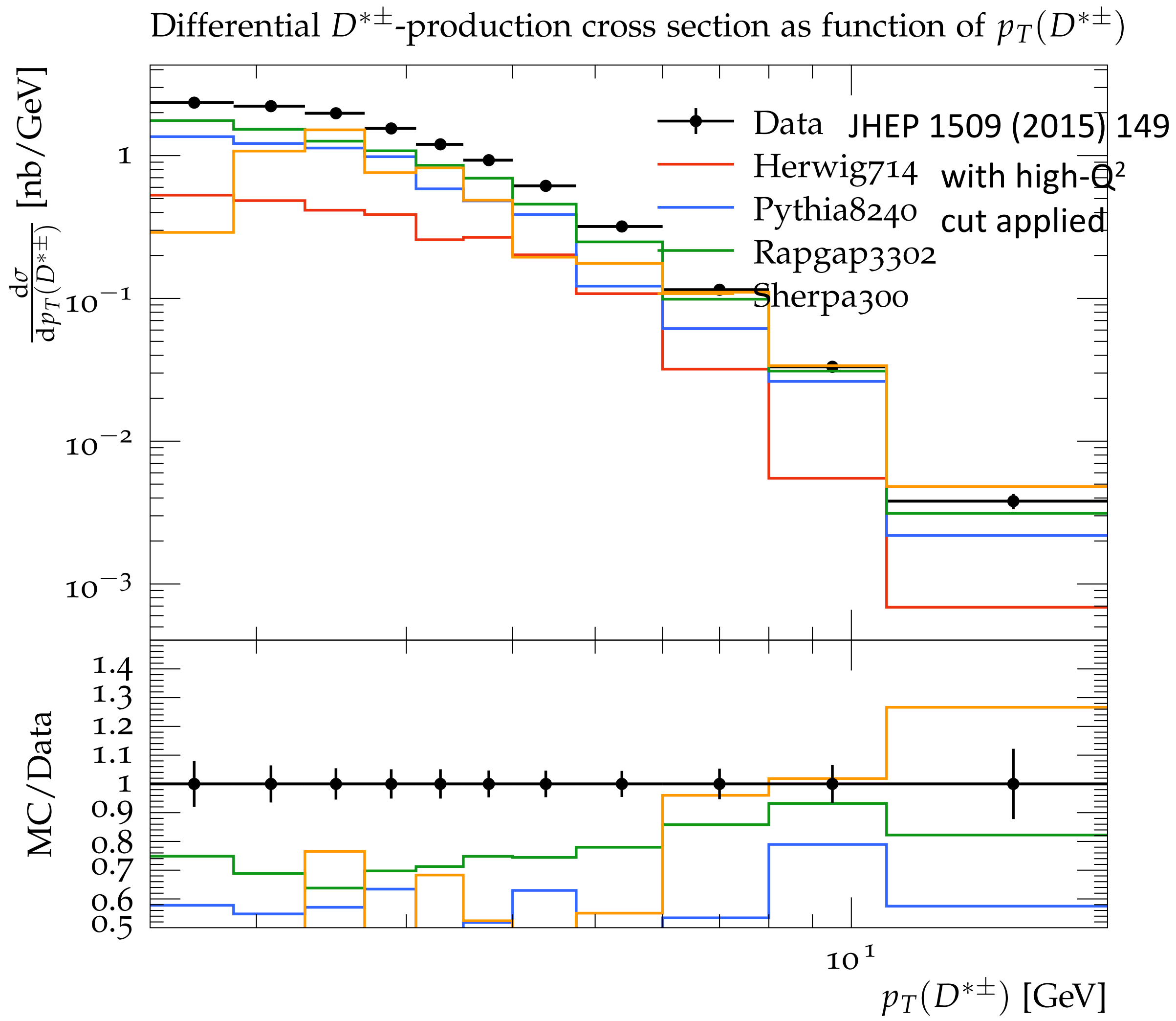
MCEG2019 20–22 February 2019

- Status of ep and eA in general-purpose MCEG
- Status of NLO simulations for ep
- TMDs and GPDs and MCEGs
- Merging QED and QCD effects

Comparisons to combined H1 and ZEUS analysis

A. Verbytskyi (MPI Munich)

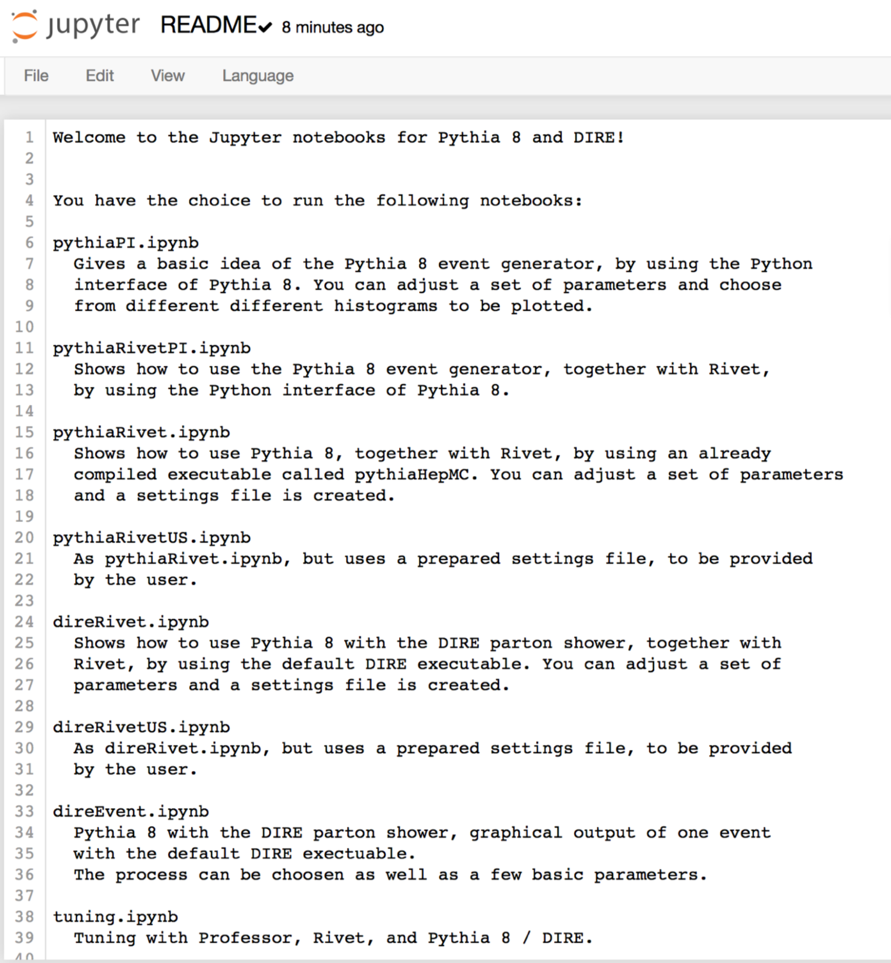




Getting started with Pythia8

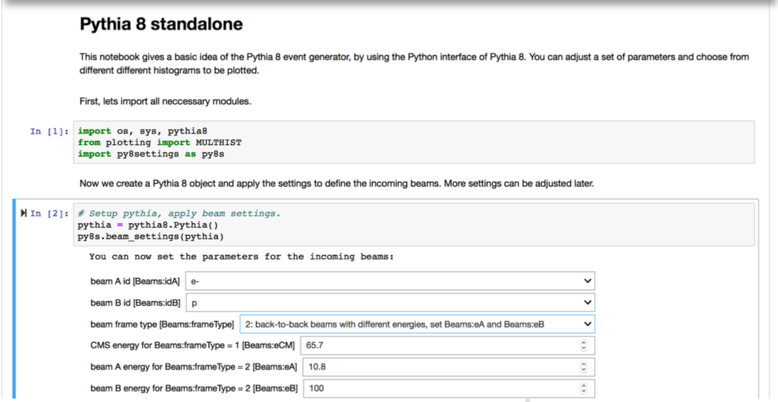
JLAB LDRD

Container for Pythia8+DIRE by Nadine Fischer (Pythia)




```
Welcome to the Jupyter notebooks for Pythia 8 and DIRE!


You have the choice to run the following notebooks:

pythiaPI.ipynb
  Gives a basic idea of the Pythia 8 event generator, by using the Python
  interface of Pythia 8. You can adjust a set of parameters and choose
  from different different histograms to be plotted.

pythiaRivetPI.ipynb
  Shows how to use the Pythia 8 event generator, together with Rivet,
  by using the Python interface of Pythia 8.

pythiaRivet.ipynb
  Shows how to use Pythia 8, together with Rivet, by using an already
  compiled executable called pythiaHepMC. You can adjust a set of parameters
  and a settings file is created.

pythiaRivetUS.ipynb
  As pythiaRivet.ipynb, but uses a prepared settings file, to be provided
  by the user.

direRivet.ipynb
  Shows how to use Pythia 8 with the DIRE parton shower, together with
  Rivet, by using the default DIRE executable. You can adjust a set of
  parameters and a settings file is created.

direRivetUS.ipynb
  As direRivet.ipynb, but uses a prepared settings file, to be provided
  by the user.

direEvent.ipynb
  Pythia 8 with the DIRE parton shower, graphical output of one event
  with the default DIRE exectuable.
  The process can be choosen as well as a few basic parameters.

tuning.ipynb
  Tuning with Professor, Rivet, and Pythia 8 / DIRE.
```

Jupyter notebook interface



Pythia 8 standalone

This notebook gives a basic idea of the Pythia 8 event generator, by using the Python interface of Pythia 8. You can adjust a set of parameters and choose from different different histograms to be plotted.

First, lets import all neccessary modules.

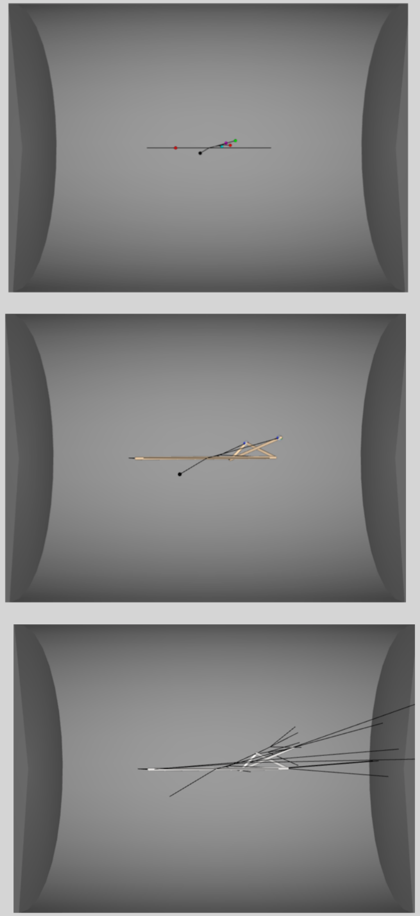
In [1]:
```
import os, sys, pythia8
from plotting import MULTIHIST
import py8settings as py8s
```

Now we create a Pythia 8 object and apply the settings to define the incoming beams. More settings can be adjusted later.

In [2]:
```
# Setup pythia, apply beam settings.
pythia = pythia8.Pythia()
py8s.beam_settings(pythia)
```

You can now set the parameters for the incoming beams:

Visualization of ep collision



MCEG–HERA comparisons and MCEG validation for ep

Rivet example

SIDIS analysis at HERMES

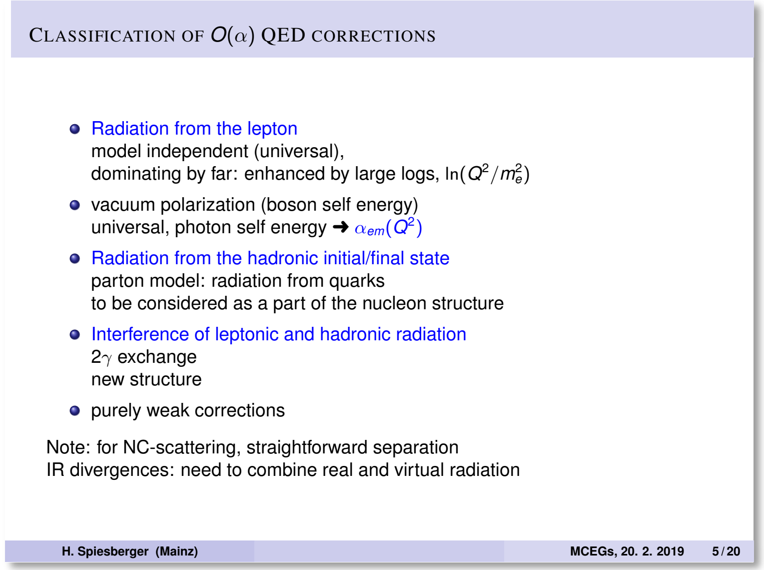
```cpp
// Extract the particles other than the lepton
const FinalState& fs = apply<FinalState>(event, "FS");
Particles particles;
particles.reserve(fs.particles().size());
const GenParticle* dislepGP = dl.out().genParticle();
foreach (const Particle& p, fs.particles()) {
  const GenParticle* loopGP = p.genParticle();
  if (loopGP == dislepGP)
    continue;
  particles.push_back(p);
}

// Apply HERMES cuts.
bool validx = (x > 0.023 && x < 0.6);
if (q2 < 1. || w2 < 10. || y < 0.1 || y > 0.85 || !validx)
  vetoEvent;

// good inclusive event, let's do bookkeeping before we look at the hadrons
dis_tot += weight;
dis_x->fill(x, weight);
dis_Q2->fill(q2, weight);

for (size_t ip1 = 0; ip1 < particles.size(); ++ip1) {
  const Particle& p = particles[ip1];

  // get the particle index, check if it is a particle of interest
  const int part_idx = get_index(p.genParticle()->pdg_id());
  if (part_idx < 0) {
    continue;
  }

  // we have a particle of interest, let's calculate the kinematics
  // z
  const double z = (p.momentum() * pProton) / (pProton * q);
  // pt
  const double pth = sqrt(p.momentum().pT2());

  // get our z index, if negative, we have a particle outside of [.2, .8]
  const int z_idx = calc_zslice(z);
  if (z_idx < 0) {
    continue;
  }

  // store the events and make cuts where necessary
  //
  // pt cut for variables not binned in pt
  if (pth > 0 && pth < 1.2) {
    mult_z[part_idx]->fill(z, weight);
    mult_zx[part_idx][z_idx]->fill(x, weight);
    mult_zQ2[part_idx][z_idx]->fill(q2, weight);
  }
  mult_zpt[part_idx][z_idx]->fill(pth, weight);
}
```

- **MCEG R&D** requires *easy* access to *data*
- data := analysis description + data points

- **HEP** existing workflow for MCEG R&D using tools such as Rivet and Professor

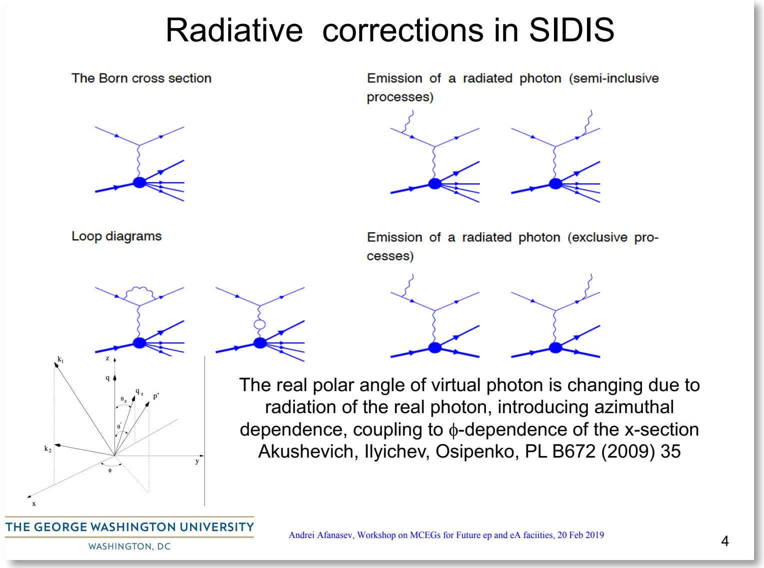
- **Detailed comparisons between modern MCEG and HERA data**
  - workshop on Rivet for ep (Feb 18—20 2019)
  - mailing list rivet-ep-l@lists.bnl.gov
  - HERA data not (yet) included in MCEG tunes

Merging QED and QCD effects



Hubert Spiesberger (Mainz): QED corrections for electron scattering

- High-precision measurements need careful treatment of radiative corrections.
- Closely related to experimental conditions need full Monte Carlo treatment (Unfolding) including simulation of hadronic final states.
- The basics are known and available …
- … but improvements are needed.



Andrei Afanasev (GWU): Semi-analytic vs. Monte-Carlo Approaches for QED Corrections to SIDIS

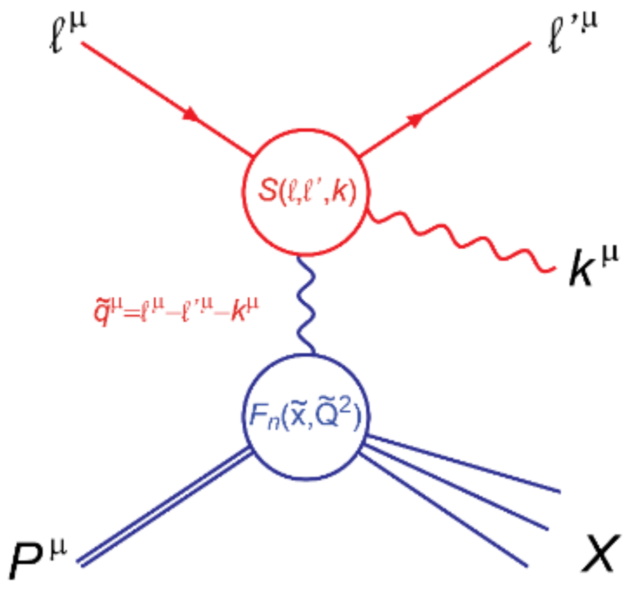
- Consistent approach to address RC for SSA in polarized SIDIS

- SSA due to two-photon exchange need to be included in analysis of SSA from strong interaction, of same size at JLAB experiments
- More detailed calculation of the two-photon exchange at quark level required: elastic scattering, inclusive, semi-inclusive, and exclusive DIS

EIC Software Consortium: Radiative Effects and MCEG

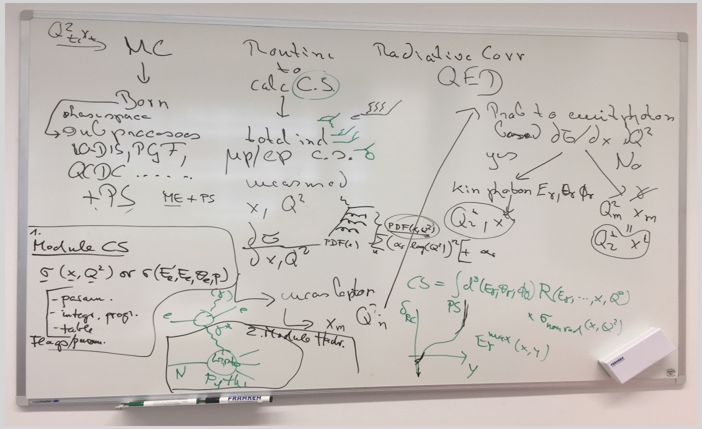
Radiative effects

- change kinematics on an event by event basis:
  - smearing of kinematic distributions
- change of virtual-photon direction:
  - false asymmetries in the azimuthal distribution of hadrons
- correction:
  - unfolding procedure, requires MCEG including radiative corrections / effects



ESC Radiative effects library

- Elke-Caroline Aschenauer, Andrea Bressan
- essential for high-precision measurements at the EIC
- collaboration with Hubert Spiesberger:
  - start back from HERACLES part of Djangoh
  - work on interface to PYTHIA6/8



MCEG2019: Next steps

- **General-purpose MCEG**s, HERWIG, PYTHIA, and SHERPA, will be significantly improved w.r.t. MCEGs at HERA time:
  - MCEG-data comparisons in Rivet will be critical to tune the MCEGs to DIS data and theory predictions.
  - The existing general-purpose MCEG should soon be able to simulate NC and CC unpolarized observables also for eA. A precise treatment of the nucleus and its breakup is needed.
  - First parton showers and hadronization models for ep with spin effects, but far more work needed for polarized ep / eA simulations.
  - Need to clarify the details about merging QED+QCD effects (in particular for eA).

- **TMD physics**
  - Vibrant community working on various computational tools for TMDs.
  - CASCADE: MCEG for unpolarized TMDs at high energy.
  - Need more verification of MCEG models with TMD theory / phenomenology.

- **GPD physics**
  - No modern MCEG available.
  - There is a path from PARTONS to a GPD MCEG, similar there is a project to extend MCEG for exclusive processes from JLAB12 to EIC.